Systematic Review and Meta-analysis of Linear and Undulating Periodized Resistance Training Programs on Muscular Strength

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Abstract

Harries, SK, Lubans, DR, and Callister, R. Systematic review and meta-analysis of linear and undulating periodized resistance training programs on muscular strength. *J Strength Cond Res* 29(4): 1113–1125, 2015—Periodization is known to improve training adaptations but the most effective periodization approach for muscular strength development for a wide variety of populations is yet to be determined. This systematic review and meta-analysis examined all studies directly comparing linear and undulating periodized resistance training programs to determine and compare their effects on muscular strength. A systematic search of the MEDLINE, SCOPUS, and SPORTDiscus databases revealed 17 studies satisfying the inclusion criteria. There were a total of 510 participants in the included studies. Sixteen studies reported significant increases in strength for both periodization approaches. Five studies reported significant differences in improvements between groups. The meta-analyses determined that there were no differences in the effectiveness of linear vs. undulating periodization on upper-body or lower-body strength. The short-term nature of studies and the previous training history of participants were identified as potential confounding factors in the interpretation of findings. The results suggest that novelty or training variety are important for stimulating further strength development. Few studies have examined the effect of periodization approaches in adolescent or athletic populations.

Key Words periodization, fitness, daily undulating, weekly undulating, performance

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Introduction

Resistance training (RT) is a specialized form of conditioning using a range of resistive loads and a variety of training modalities designed to enhance health, fitness, and sports performance (9). Participation in RT results in numerous performance- and health-related benefits in adolescent and adult populations (9,22,33). These benefits include improvements in athletic performance, musculoskeletal health, muscular strength, power and endurance, motor performance including jumping ability, balance and coordination, and cardiovascular and metabolic health (9,11,14,22,33,38,40). The American College of Sports Medicine (ACSM) recommends the use of periodized RT programs based on evidence that such programs are more effective than nonperiodized programs (33). Periodization is the systematic planning and structuring of training variables (intensity, volume, frequency, and rest) throughout designated training timeframes aimed at maximizing performance gains and minimizing the potential for overtraining or decrements in performance (3,5,16,25–27,29,32,35,36).

There is debate regarding the terminology used to describe periodized programs (13,19,31) and the most effective manipulation of key training variables to improve neuromuscular performance for a wide variety of populations is yet to be determined (5,28,32,35,36). Two of the most commonly referred to periodization models in the literature are linear periodization (LP) and undulating periodization (UP). Linear periodization has been described as involving the breakdown of the training year into weekly (microcycle), monthly (block or mesocycle), and multi-monthly (cycle or macrocycle) periods. A key characteristic of LP is an initial high volume and low intensity of training with gradual increases in intensity and decreases in volume within and across training periods (3,5,15–17,20,25–27,33,35–37). Undulating periodization has been described as more frequent, daily, weekly, or biweekly variation of intensity and volume and generally uses repetition maximum zones to prescribe exercise intensity (5,16,17,20,26,28,29,32,33,35–37). Undulating periodization is commonly identified as daily undulating periodization (DUP) or weekly undulating periodization (WUP) depending on whether volume and intensity of RT is manipulated on a daily or weekly basis. It has been proposed that these nonlinear manipulations of volume and intensity, providing more frequent changes in stimuli and periods of recovery, are more conducive to strength gains (3,5,16,26,27,32,35,36).

A number of studies have compared the effects of LP RT programs with UP or nonlinear periodized programs. The aims of this review were to (a) systematically identify and examine all studies directly comparing linear and undulating periodized RT programs and to synthesize the results, (b) quantitatively compare linear and undulating periodized RT programs' effects on muscular strength using meta-analysis, (c) evaluate the risk of bias in previous studies and provide recommendations to improve the quality of future studies, and (d) review the study populations in which the comparisons of these resistance training programs have been investigated.

Methods

Experimental Approach to the Problem

The conduct and reporting of this review was guided by the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement (23). A comprehensive search of the MEDLINE, SCOPUS, and SPORTDiscus databases was conducted on April 27, 2012. A librarian assisted in the development of unique search strategies for the different databases. No year restriction was placed on the search. Titles and abstracts of identified articles were checked for relevance in the first stage of screening. In the second stage, full-text articles were retrieved and considered for inclusion. Finally, the reference lists of included articles were screened for additional articles. The search was updated to the July 28, 2014, during the revision process.

Studies were assessed for eligibility based on the following inclusion criteria: (a) participants were from a nonclinical population, (b) study compared the use of a linear RT program (LP) with an undulating periodized RT program (UP) (free weights, bodyweight resistance [including plyometrics], elastic tubing, machine weights, isokinetic devices), (c) study involved a randomized controlled trial (RCT) or quasi-experimental design, (d) study included a quantitative assessment of muscular strength, and (e) study was published in English. Conference abstracts, dissertations, theses, and articles published in non–peer-reviewed journals were not included. No restriction was placed on participant age or training experience.

Studies had to meet the following additional criteria to be included in the meta-analysis: (a) assessed muscular strength by a bench press, squat, or leg press repetition maximum test; and (b) data were reported as means and *SD*s for the linear and undulating periodized groups at post-test. Separate meta-analyses were conducted for studies that assessed bench press, squat, or leg press. Authors were contacted in attempts to obtain further details when required.

Statistical Analyses

Meta-analyses have been strongly emphasized for their utility to provide a quantitative summary of treatment effects and their use as a tool to bridge the gap between the science and practice of exercise prescription (30). All meta-analyses were performed in RevMan (6). The meta-analyses sought to determine the effect of the periodization approaches on upper- and lower-body muscular strength. Muscular strength was considered a continuous data variable; therefore, the mean difference (MD) with 95% confidence intervals were used to determine effect measures. The inverse-variance random effects model was used for the meta-analysis procedure because of studies being performed with varied populations and methods. The χ^2 and the I^2-Index tests were used to examine statistical heterogeneity. A previous meta-analysis provided the following guide for the interpretation of heterogeneity based on the I^2-Index: 0–40% might not be important, 30–60% may represent moderate heterogeneity, 50–90% may represent substantial heterogeneity, and 75–100% considerable heterogeneity (8,14).

Studies were assessed for "risk of bias" using criteria adapted from the Consolidated Standards of Reporting Trials (CONSORT) statement by 2 authors independently, and in the case of disagreement, further discussion was undertaken to achieve consensus. A "risk of bias" score for each study was completed on an 8-point scale by assigning a value of 0 (absent or inadequately described) or 1 (explicitly described and present) to each methodological item listed in Table 1. Studies that scored 0–2 were regarded as having a high risk of bias, studies that scored 3–5 were classified as having a medium risk of bias, and those that scored 6–8 were classified as having a low risk of bias.

Results

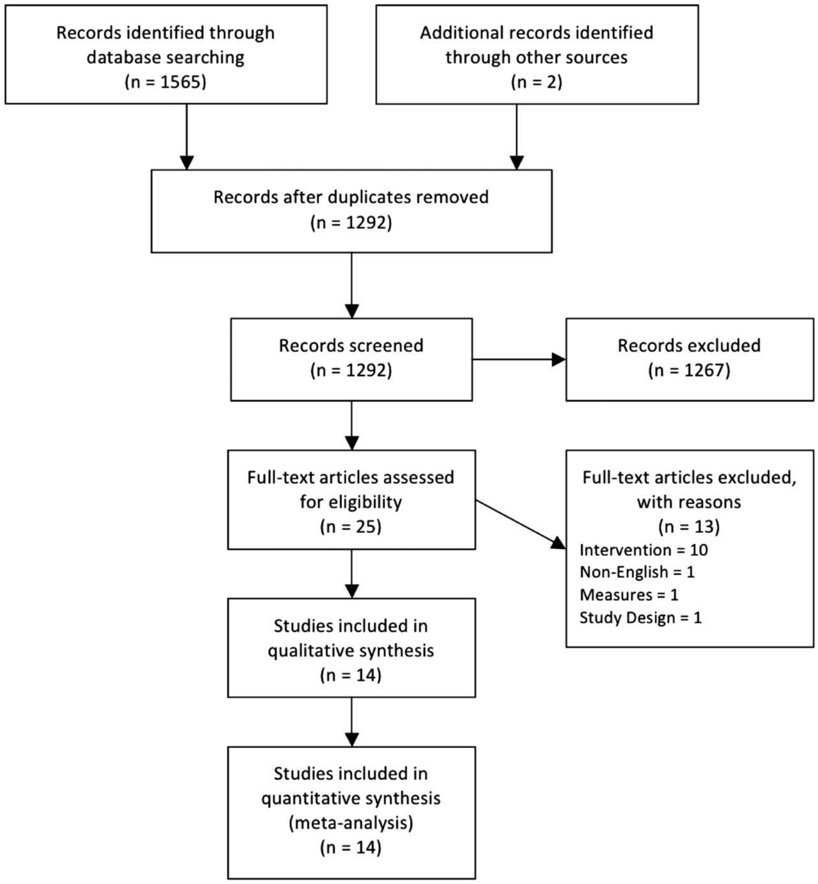
The flow of studies through the review process is reported in Figure 1. Twenty-five full-text articles were assessed; 17 met the inclusion criteria (Table 2), and 17 were included in the meta-analyses. Twelve studies compared the effectiveness of LP and DUP RT programs (7,12,15–17,20,26,27,29,32,35,36). Three studies compared LP and WUP RT programs (1,3,39). One study compared LP, WUP, and DUP programs (5), and 1 study compared an LP program with a program incorporating both WUP and DUP (37).

There were a total of 510 participants in the included studies. Twelve of these studies assessed males only, 3 studies females only and 2 studies assessed both males and females. The average age of participants was 24 years (*SD*: 5), with a range of 19–39 years. One study did not report participant age. Resistance training experience was reported in all studies. Seven studies were conducted in untrained participants (<1 year RT experience), whereas participants in 10 studies were identified as trained (≥1 year RT experience). No studies were conducted in advanced resistance trained participants (>5 years RT experience). Participants in 10 studies were identified as recreational trainers, in 1

TABLE 1. Risk of bias assessment.*

Study	(i) Were the groups comparable at baseline on key characteristics?	(ii) Did the study randomize participants? And was the randomization procedure adequately described and carried out?	(iii) Did the study report a power calculation and was the study adequately powered to detect intervention effects?	(iv) Were the assessors blinded to treatment allocation at baseline and posttest?	(v) Did at least 80% of participants complete follow-up assessments?	(vi) Did the study analyses account for potential differences at baseline?	(vii) Did the study report 95% confidence intervals?	(viii) Did the study equate volume and intensity between groups?	Total
Baker et al. (3)	1	0	0	0	0	1	0	1	3
Rhea et al. (35)	1	0	0	0	1	1	0	1	3
Hoffman et al. (17)	0	0	0	0	0	1	0	0	1
Rhea et al. (36)	1	0	0	0	1	1	0	1	3
Buford et al. (5)	1	0	0	0	1	1	0	1	3
Peterson et al. (29)	0	0	0	0	1	1	0	1	2
Hartmann et al. (15)	0	0	0	0	1	1	0	0	2
Hoffman et al. (16)	0	0	0	0	0	1	0	0	1
Kok et al. (20)	1	0	0	0	1	1	1	1	4
Monteiro et al. (27)	1	0	0	0	1	1	0	1	3
Prestes et al. (32)	1	0	0	0	1	1	0	1	3
Vanni et al. (39)	1	0	0	0	1	1	0	1	3
Miranda et al. (26)	1	0	0	0	1	1	0	1	3
Simao et al. (37)	1	0	0	0	1	1	0	1	3
Apel et al. (1)	1	0	0	0	1	1	0	1	4
de Lima et al. (7)	1	0	0	0	1	1	0	1	4
Franchini et al. (12)	1	0	0	0	0	1	0	1	3

*Yes = 1; no = 0.



Search strategy used in MEDLINE, SCOPUS, SPORTDiscus databases
'resistance training', resistance, 'strength training', 'weight training', 'weight lifting', 'fitness training', training, strength, 'muscle strength', periodis*, periodiz*, linear, undulating, non-linear, 'non linear'

Figure 1. Flow of studies.

study participants were sedentary, 2 studies were conducted in American football athletes, 1 study was conducted with Judo athletes, and participants in 2 studies were tactical service operators (firefighters or military personnel).

The mean duration of RT programs was 12.6 ± 4.1 weeks. Nine of the studies were of 12-week and 3 studies were of 9-week duration. Mean training frequency was 3.2 ± 0.7 sessions per week. Session duration was not reported in 10 of the 17 studies. Most RT programs (11 studies) used a combination of both multi-joint and single-joint free weight and machine-based exercises. Five studies consisted of mostly multi-joint free weight exercises (3,16,17,27,29). One study used single-joint machine-based exercises only (15).

Maximal strength was assessed in all studies. Sixteen studies assessed upper-body strength by a repetition maximum bench press test. Lower-body strength was assessed using a repetition maximum squat test in 7 studies and a leg press repetition maximum test in 7 studies. Of the included studies, 16 reported statistically significant increases in maximal strength for both LP and UP RT programs (1,3,5,7,12,15,16,20,26,27,29,32,35–37,39). Twelve of these studies found no significant difference in maximal strength gains between LP and UP RT programs (3,5,7,12,15,16,20,26,29,32,36,39). Three studies found a significant difference favoring UP RT programs (27,35,37), whereas 2 studies found a significant difference favoring the LP group (1,17).

After the initial risk of bias assessment, there was 96% agreement between authors and full consensus was achieved after discussion (Table 1). There was a high risk of bias in 4 studies (23.5%) and a medium risk in 13 (76.5%) studies. No studies had a low risk of bias. Thirteen studies reported randomizing participants to groups; however, no study adequately described the randomization process. No studies

Table 2. Characteristics of included studies.*

Study	Participants: Participant numbers, gender, and mean age	Participants: Resistance training experience	Training programs: Study period	Training programs: Sessions per week	Training programs: Session duration	Training programs: Training attendance/ compliance rate	Training programs: Description of resistance training program
Baker et al. (3)	33 (M) recreational participants; NP control group ($n = 9$): 19.0 ± 1.1 y; LP group ($n = 8$): 20.2 ± 1.2 y; WUP group ($n = 5$): 21.4 ± 5.0 y	Trained	12 wks	3/wk	Not reported	Not reported	Nonperiodized vs. LP or WUP; resistance training on maximal strength and vertical jump; majority free weight multi-joint exercises
Rhea et al. (35)	20 (M) recreational participants; LP group ($n =$ 10): 21.2 ± 3.1 y; DUP group ($n = 10$): 20.2 ± 2.4 y	Trained	12 wks	3/wk	40 min	Not reported	LP vs. DUP resistance training on 1RM strength; periodization of loading was prescribed for the leg press and bench press for each group; additional exercises identical for each group
Hoffman et al. (17)	28 (M) freshman American football participants; LP group ($n = 14$): age not reported; DUP group ($n =$ 14): age not reported	Trained	12 wks	2/wk	Not reported	LP group performed squat in 83.8 ± 15.6% and bench press in 85.7 ± 13.4% of workouts; DUP group performed squat in 90.8 ± 9.2% and bench press in 93.9 ± 5.4% of workouts	LP vs. DUP in-season resistance training on 1RM strength; majority free weight multi-joint exercises
Rhea et al. (36)	30 (M) and 30 (F) recreational participants; LP group ($n =$ 20): 21 ± 2.4 y; reverse LP group ($n = 20$): 22 ± 1.6 y; DUP group ($n = 20$): 21 ± 1.9 y	Trained	15 wks	2/wk	Not reported	Participants required to attend 28 of the 30 training sessions	LP vs. reverse LP or DUP resistance training on muscular endurance; single-joint isolation exercises
Buford et al. (5)	28 (M) and 10 (F) recreational participants; LP group ($n =$ 9): 22.67 ± 3.61 y; DUP group ($n = 10$): 23.90 ± 5.11 y; WUP group ($n = 9$): 20.11 ± 1.54 y	Untrained	9 wks	3/wk	Not reported	90% attendance required	LP vs. DUP or WUP resistance training on 1RM strength; a mixture of both free weight and machine-based multi-joint exercises

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Peterson et al. (29)	14 (M) firefighter academy participants; LP group ($n =$ 7): 21.6 y; DUP group ($n =$ 7): 22.1 y	Trained	9 wks	3/wk	60–90 min	Participants required to attend 25 of the 27 training sessions	LP vs. DUP resistance training on strength and power; majority free weight multi-joint exercises but also included plyometric movements and machine-based exercises
Hartmann et al. (15)	40 (M) recreational participants; LP group ($n = 13$): 24.31 ± 3.17 y; DUP group ($n = 14$): 25.14 ± 3.98 y; non-training control group ($n = 13$): 24.77 ± 3.09 y	Trained	14 wks	3/wk	Not reported	Participants required to attend 39 of the 42 training sessions	LP vs. DUP resistance training on strength and power in the bench press; intervention consisted of training bench press exercise only
Hoffman et al. (16)	51 (M) American football players; NP control group ($n = 17$): 19.9 ± 1.3 y; LP group ($n = 17$): 19.5 ± 1.1 y; DUP group ($n = 17$): 19.6 ± 0.9 y	Trained	15 wks	4/wk	Not reported	Not reported	NP vs. LP or DUP resistance training on strength and power; a majority of free weight multi-joint exercises; also included a number of single-joint isolation exercises
Kok et al. (20)	20 (F) recreational participants; LP group ($n = 10$): 19.6 ± 1.6 y; DUP group ($n = 10$): 19.9 ± 2.3 y	Untrained	9 wks	3/wk	60 min	100% compliance for 18 participants; 97% compliance for 2 participants	LP vs. DUP resistance training on strength and power; a mixture of both free weight and machine-based multi-joint and single-joint isolation exercises
Monteiro et al. (27)	27 (M) recreational participants; 19.9 ± 2.3 y; NP group ($n = 9$): 26.6 ± 2.2 y; LP group ($n = 9$): 27.6 ± 2.7 y; DUP group ($n = 9$): 28.1 ± 2.9 y	Trained	12 wks	4/wk	Not reported	Not reported	NP vs. LP or DUP resistance training on maximal strength; majority free weight multi-joint exercises
Prestes et al. (32)	40 (M) recreational participants; LP group ($n = 20$): 22.3 ± 7.5 y; DUP group ($n = 20$): 21.2 ± 9.2 y	Trained	12 wks	4/wk	50 min	Ø 98% compliance for all participants	LP vs. DUP resistance training on maximal strength; a mixture of both free weight and machine-based multi-joint and single-joint isolation exercises
Vanni et al. (39)	27 (F) recreational participants; LP group ($n = 14$): 39.5 ± 0.60 y; WUP group ($n = 13$): 39.7 ± 0.59 y	Untrained	28 wks	3/wk	70–90 min	2 participants dropped out of the study; there was 100% compliance with remaining participants	LP vs. WUP resistance training on muscular and bone responses in premenopausal women; a mixture of both free weight and machine-based multi-joint and single-joint isolation exercises

Miranda et al. (26)	20 (M) recreational participants; LP group (n = 10): 26 ± 6 y; DUP group (n = 10): 26.5 ± 5 y	Trained	12 wks	4/wk	Not reported	Not reported	LP vs. DUP resistance training on strength; a mixture of both free weight and machine-based multi-joint and single-joint isolation exercises
Simao et al. (37)	30 (M) Brazilian Navy participants; LP group (n = 10): 29.8 ± 1.9 y; WUP/DUP group (n = 11): 30.2 ± 1.1 y; non-training control group (n = 9): 25.9 ± 3.6 y	Untrained	12 wks	2/wk	Not reported	100% compliance for all participants	LP vs. WUP/DUP resistance training on 1RM strength; a mixture of both free weight and machine-based multi-joint and single-joint isolation exercises
Apel et al. (1)	42 (M) recreationally active participants; LP (traditional) group (n = 14): 23 ± 2.8 y; WUP group (n = 14): 22 ± 1.9 y; non-training control group (n = 14): 22 ± 2.3 y.	Untrained	12 wks	3/wk weeks 1–2; 4/wk weeks 3–12	45 min	5 participants dropped out of the study; there was 100% compliance with remaining participants	LP (traditional) vs. WUP resistance training on 10RM strength; a mixture of both free weight and machine-based multi-joint and single-joint isolation exercises
de Lima et al. (7)	28 (F) sedentary participants; LP group (n = 10): 25.20 ± 4.35 y; DUP group (n = 10): 27.40 ± 2.80 y; non-training control group (n = 8): 23.40 ± 1.29 y	Untrained	12 wks	4/wk	Not reported	Not reported	LP vs. DUP resistance training on 1RM strength and maximum repetitions at 50% 1RM; a mixture of both free weight and machine-based multi-joint and single-joint isolation exercises
Franchini et al. (12)	13 (M) judo athlete participants; LP group (n = 6); DUP group (n = 7); age range of participants: 18–35 y	Untrained in regards to resistance training; trained athletes	8 wks	3/wk	Not reported	7 participants dropped out of the study; there was 100% compliance with remaining participants	LP vs. DUP resistance training on 1RM strength and strength endurance and specific judo tests; a mixture of both free weight and machine-based multi-joint and single-joint isolation exercises

	Methods			Results	
Study	Study design	Outcomes	Analysis	Results	Effect sizes reported for primary outcomes
Baker et al. (3)	QEXP	1RM squat; 1RM bench press; vertical jump	ANCOVA	Significant improvements in 1RM squat for all groups (26.1% NP; 27.7% LP; 28.4% WUP); significant improvements in 1RM bench press for all groups (12.5% NP; 11.6% LP; 16.4% WUP)	No

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Rhea et al. (35)	QEXP	1RM leg press; 1RM bench press	ANOVA with repeated measures	Both groups increased strength significantly; 1RM bench press increased 14.4% for LP group and 28.8% for DUP group; 1RM leg press increased 25.61% for LP group and 55.8% for DUP group; significantly greater percent gains for DUP compared with LP group	No
Hoffman et al. (17)	QEXP	1RM squat; 1RM bench press	ANOVA with repeated measures	Significant improvement in 1RM squat for LP but not for DUP; no significant improvement for either group in 1RM bench press	No
Rhea et al. (36)	QEXP	Local muscular endurance test (maximum reps on leg extension at load of 50% body mass); 1RM leg extension	ANOVA with repeated measures	All groups significantly increased muscular endurance and 1RM strength; muscular endurance increased 55.9, 54.5, and 72.8% for LP, DUP, and reverse LP, respectively; no difference between groups; 1RM strength increased 9.1, 9.8, and 5.6% for LP, DUP, and reverse LP groups, respectively; no difference between groups	Yes
Buford et al. (5)	QEXP	1RM leg press; 1RM bench press	ANCOVA	Significant increases in leg press and bench press strength for all groups; no significant difference between groups although DUP resulted in a lower percentage change in 1RM leg press and bench press	No
Peterson et al. (29)	QEXP	1RM squat; 1RM bench press; vertical jump	ANOVA with repeated measures	Significant increases in both groups for 1RM squat and 1RM bench press strength and vertical jump; greater % change in 1RM squat, 1RM bench press, and vertical jump for DUP group than LP	No
Hartmann et al. (15)	QEXP	1RM bench press	ANOVA	Significant improvements in 1RM bench press for LP (14.6 ± 11.0%) and DUP (10.0. ± 4.5%) groups; no difference between groups; significant difference for both experimental groups compared with control group who achieved no significant change (1.38 ± 5.84%)	No
Hoffman et al. (16)	QEXP	1RM squat; 1RM bench press; vertical jump; seated medicine ball throw	ANOVA with repeated measures	All groups significantly improved 1RM squat and bench press strength; no difference between groups; all groups significantly improved vertical jump performance	No
Kok et al. (20)	QEXP	1RM squat; 1RM bench press; loaded squat jump	ANOVA with repeated measures	Significant improvements in 1RM squat for both groups (34.8%, ES: 1.88 LP; 41.2%, ES: 2.10 DUP); significant improvements in 1RM bench press for both groups (21.8%, ES: 0.88 LP; 28.3%, ES: 1.05 DUP); increases in jump height for both LP (28.0%, ES: 1.15) and DUP (21.5%, ES: 0.96) groups were observed	Yes

Monteiro et al. (27)	QEXP	1RM leg press; 1RM bench press	ANOVA	Only DUP significantly improved 1RM bench press strength; significant improvements in 1RM leg press strength DUP and LP; no improvement in 1RM leg press for NP	No
Prestes et al. (32)	QEXP	1RM leg press; 1RM bench press; 1RM standing arm curl	ANOVA with repeated measures	Significant improvements in 1RM leg press (24.71%, LP; 40.61%, DUP), 1RM bench press (18.2%, LP; 25.08%, DUP), and 1RM standing arm curl for both groups (14.15%, LP; 23.53%, DUP); no significant differences between groups	No
Vanni et al. (39)	QEXP	1RM leg press; 1RM bench press	Linear mixed models	Significant improvements in 1RM leg press (48.2 ± 6.1% LP; 51.8 ± 8.0% WUP) and 1RM bench press (27.0 ± 4.7% LP; 45.9 ± 8.4% WUP); no statistically significant differences between groups	No
Miranda et al. (26)	QEXP	1RM and 8RM leg press; 1RM and 8RM bench press	ANOVA	Significant increase in 1RM leg press (10%, ES: 1.23, LP; 18%, ES: 1.55, DUP); and 1RM bench press for both groups (15%, ES: 0.75, LP; 16%, ES: 1.02, DUP); no significant differences between groups	Yes
Simao et al. (37)	RCT	1RM bench press; 1RM lat pull down; 1RM machine triceps extension; 1RM bicep curl	ANOVA	Both training groups increased 1RM lat pull down (LP ES: 0.77; WUP/DUP ES: 0.56), 1RM bicep curl (LP ES: 0.83; WUP/DUP ES: 0.98), and 1RM tricep extension (LP ES: 0.81; WUP/DUPES: 1.53); only WUP/DUP significantly increased 1RM bench press (ES: 1.74)	Yes
Apel et al. (1)	RCT	10RM squat; 10RM bench press; 10RM leg extension; 10RM lat pull down; 10RM shoulder press	ANOVA	Both training groups significantly increased 10RM squat (LP 54%; WUP 34%) and bench press (LP 24%; WUP 19%) at 12 wk; but only the LP (traditional) group showed significant increases in 10RM strength from week 8 to week 12	No
de Lima et al. (7)	RCT	Leg press 1RM; bench press 1RM; standing arm curl 1RM; maximum repetitions using 50% of 1RM on leg press, bench press and standing arm curl	ANOVA	Significant increases in 1RM leg press (ES: 2.99, LP; ES: 1.73, DUP), 1RM bench press (ES: 1.77, LP; ES: 0.95, DUP), and 1RM arm curl (ES: 1.30, LP; ES: 1.19, DUP) for both groups; no significant differences between groups	Yes
Franchini et al. (12)	QEXP	1RM squat; 1RM bench press; 1RM row; maximal isometric handgrip test; standing long jump; special judo fitness test	ANOVA	Significant improvements in 1RM squat, bench press and row for both groups; significant improvements in maximal isometric handgrip strength for both groups; no significant differences between groups	No

*M = male; F = female; ES = effect size; NP = nonperiodized; LP = linear periodization; WUP = weekly undulating periodization; DUP = daily undulating periodization; 1RM = 1 repetition maximum; ANOVA = analysis of variance.

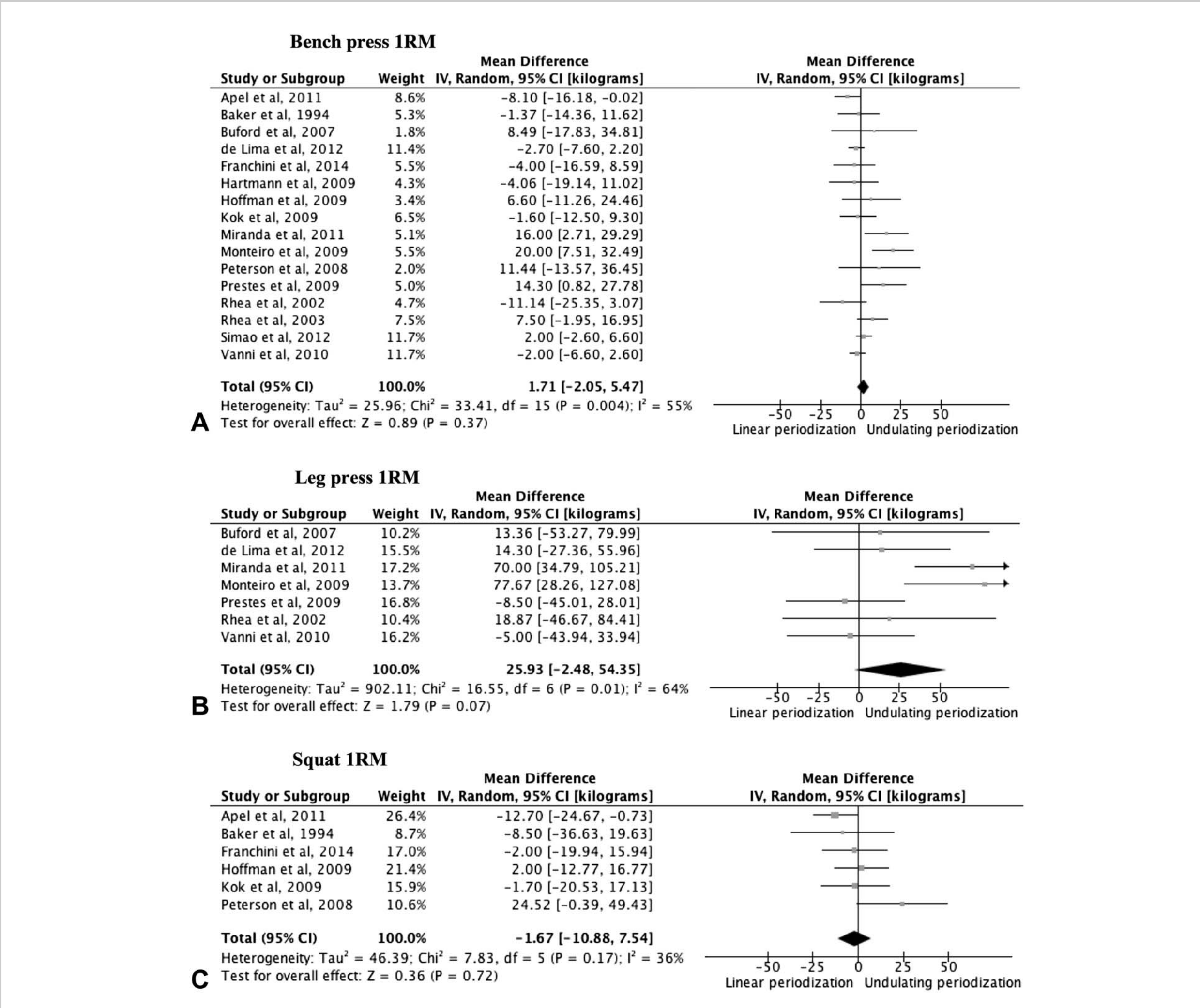

Figure 2. Meta-analyses of linear and undulating periodization on muscular strength.

reported using blinded assessors. No studies reported a power calculation to determine whether their study was adequately powered to detect their hypothesized effects. In addition, effect sizes were reported in only 5 of the included studies (7,20,26,36,37). Eighty percent of participants completed follow-up assessments in 13 studies. Analyses in all studies accounted for potential baseline differences. All but 3 studies equated the volume and intensity between training groups.

Meta-analyses

Sixteen studies were evaluated in a meta-analysis comparing 1 repetition maximum (1RM) bench press at postintervention (Figure 2). Overall, the studies were found to be moderately heterogeneous ($\chi^2 = 33.41$, $df = 15$ [$p = 0.004$], $I^2 = 55\%$). The meta-analysis showed no clear effect for either LP or UP (MD = 1.71 [−2.05 to 5.47] kg, $Z = 0.89$ [$p < 0.37$]). Seven studies were evaluated in a meta-analysis comparing 1RM leg press at postintervention (Figure 2). These studies had significant heterogeneity ($\chi^2 = 16.55$, $df = 6$ [$p = 0.01$], $I^2 = 64\%$). No clear effect was shown for either LP or UP (MD = 25.93 [−2.48 to 54.35] kg, $Z = 1.79$ [$p = 0.07$]). Seven studies were evaluated in a meta-analysis comparing 1RM squat at postintervention (Figure 2). These studies were homogenous ($\chi^2 = 7.83$, $df = 5$ [$p = 0.17$], $I^2 = 36\%$). No effect favoring LP or UP was found (MD = −1.67 [−10.88 to 7.54] kg, $Z = 0.36$ [$p = 0.72$]).

Discussion

This review identified 17 studies that directly compared LP and UP programs. Studies were mostly conducted in young adult males with limited RT experience. Most studies found no differences between the 2 periodization models, and this was supported by the findings of the meta-analyses where no difference was identified for both upper- and lower-body strength. There is substantial room to improve the quality of future studies comparing training manipulations to reduce the risk of bias. There is also a lack of studies investigating more athletic or highly resistance trained populations as well as adolescents and over long time frames.

The RT programs evaluated in this review were predominantly short-term interventions and only 4 studies had a duration greater than 12 weeks. Two studies found DUP RT resulted in increased strength in the initial weeks of the intervention with no increase in strength with LP RT until later stages of the intervention (27,35). The short-term nature of these interventions makes it difficult to draw conclusions regarding the long-term effectiveness of LP or UP. Longer-term interventions are needed in order to assess the purported advantage of greater variation in UP being more effective at breaking strength plateaus than LP (5,10,17,20,26,29,35).

The majority of study participants were adult males and none of the studies investigated the effects of LP and UP in adolescents. Additionally, supporting evidence for both forms of periodization is lacking in novice and athletic populations. Generalized training theories underpin the rationale for periodized training programs (32,35,36,40). Selye's General Adaptation Syndrome states that if a stress or bout of exercise is experienced by a system, the system will respond with a temporary decrease in performance followed by restitution returning to or above the initial level of physical fitness (2,40). This enhancement of physical fitness is termed supercompensation (2,40) and is the primary purpose of all training interventions where an improvement in physical fitness is sought. If the applied stress remains at the same magnitude (intensity, volume and frequency) the system will accommodate to this stress and no further improvements in physical fitness will occur (2,40). To avoid this accommodation, training programs must be varied over time (40).

Previous training history and training status will influence adaptations to further training interventions, particularly in respect to muscular strength. Over a 4-week to 2 year period muscular strength increases of 40, 16, 10, and 2% are representative of the expected improvements in untrained, trained, advanced and elite resistance trained individuals, respectively (21,33). Most participants in this review had some prior RT experience and were identified by study authors as trained. When planning training interventions it is important to consider generalized theories of training adaptation and in particular the initial level of physical fitness or physical preparedness of participants. The description of study participants' previous training history was poorly reported in most of the included studies. For example, Rhea et al. (35) indicated that all participants in their 12-week study reported undertaking RT equivalent to a LP approach during the 2 years prior to the study but did not describe the volume or frequency of training. They found a significant difference favoring DUP for strength improvement only in the first 6 weeks of the intervention. However, no significant difference in strength gains between groups was found in the last 6 weeks of the intervention. Prior experience with LP RT creates the potential for UP to provide a more novel stimulus. It is reasonable to suggest that the novelty or variation in stimulus compared to participants' previous training experience is of greater importance for eliciting strength improvements and overcoming accommodation than the specific type of periodization approach employed. There is a need for authors to clearly describe the training experience of their participants with different periodization approaches.

The majority of studies included in this review found significant increases in muscular strength for both periodization approaches, whereas significant differences between approaches were rarely found. One possibility is that studies were underpowered to detect statistically significant differences. Considering the small sample sizes often involved in sports science studies, the reporting of effect sizes may be more practically meaningful in RT interventions (4,18,34). Only 5 of the studies included in this review reported effect sizes (7,20,26,36,37). In a previous review, Rhea (34) reported that the effect sizes in RT studies were much larger than those typically observed in the social/behavioral fields. He recommended scales for assessing the practical significance of effect sizes in RT research based on participant's training status (34). This scale highlights the importance for RT research studies to adequately describe the training history and background of participants. Comprehensive reporting of effect sizes in the scientific literature will enable strength and conditioning professionals to use theoretical knowledge and implement practical evidence-based training programs. Further within group variations in baseline strength and responsiveness may also influence the capacity to detect differences between training approaches.

To the authors knowledge this is the first systematic review and meta-analysis comparing linear and undulating periodized RT programs. A strength of a systematic review is that the criteria for inclusion is determined prior to the search and is designed to minimize reviewer bias in regards to what is included. This objectivity is strengthened by adherence to the PRISMA reporting guidelines and CONSORT statement. A strength of combining a systematic search with a meta-analysis is that it allows data from multiple studies to be combined to determine an outcome. This is particularly advantageous when studies have small sample sizes and risk an inability to identify differences due to lack of statistical power. A number of limitations should be noted. Firstly, there may be bias in the selection of studies as abstracts, theses, or studies published in non peer-reviewed journals were not included. Additionally, there was considerable heterogeneity between studies and no study adequately described the randomization of participants. Therefore, caution should be taken in the interpretation of the meta-analysis results.

Practical Applications

The results of this systematic review and meta-analysis reveal that both LP and UP RT programs can increase maximum strength substantially, but no clear evidence favoring either periodization approach was found for the development of upper or lower body strength. The results suggest that novelty or training variety are important for stimulating further strength development. When the work performed is equal, neither periodized approach is necessarily superior and either approach can be used to provide variety and therefore enhance adaptation. Potentially the implementation of short training blocks, of 2–6 weeks duration, using either LP or UP RT within current training regimes may provide an adequate and novel stimulus to promote further strength increases and overcome plateaus. Therefore, strength and conditioning professionals are advised to design periodized training programs taking into account the RT principle of "variety" to prevent stagnation and accommodation to a particular training approach. Careful consideration should be given to the previous training history and current training status of participants.

Further research is needed in adolescent, athletic, and possibly for rehabilitation (24) populations to investigate the effects of different periodized approaches to RT. Furthermore, longer-term studies are also needed to determine and compare the long-term effectiveness of LP and UP RT on strength development. Researchers are advised to adequately report the previous training history of participants, stratify assignment to groups on the basis of prior training experience, or implement standardized pre-intervention training to reduce the influence of training history on intervention effects.

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